

Recent Results on Galactic Sources from the Fermi Large Area Telescope

*Elizabeth Hays
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*On behalf of the Fermi LAT
Collaboration*

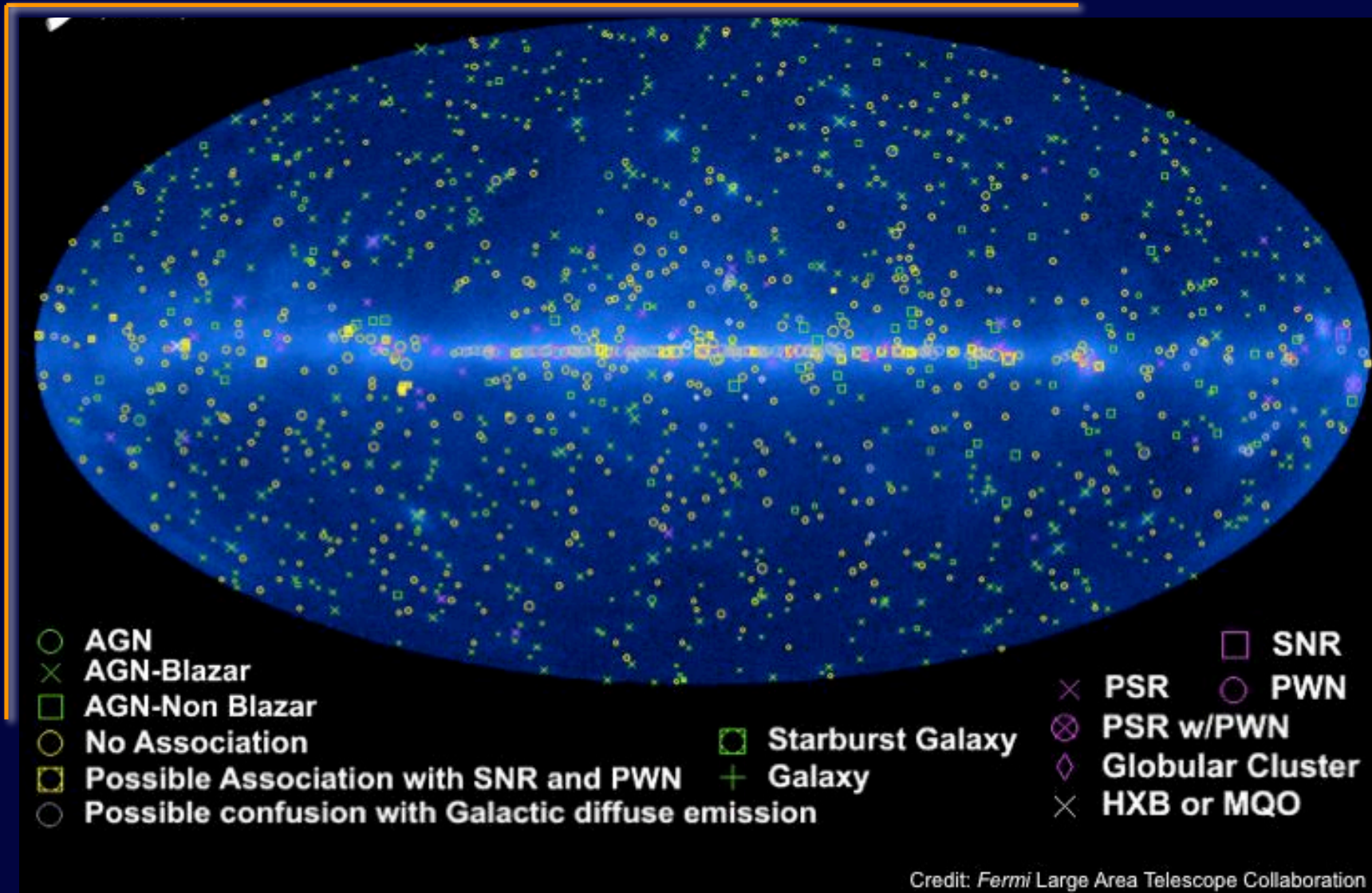


Galactic Results from LAT

- ✦ Galactic sources in the 1FGL Catalog
 - ✦ New GeV source classes in the Galaxy
- ✦ Recent Highlights
 - ✦ Pulsars
 - ✦ Pulsar Wind Nebulae (4+)
 - ✦ Supernova Remnants (5+)
 - ✦ Binaries (2 gamma, 1 MQO)



The 1FGL Catalog



May 28, 2010

March 18 2010 Astro pic of the day

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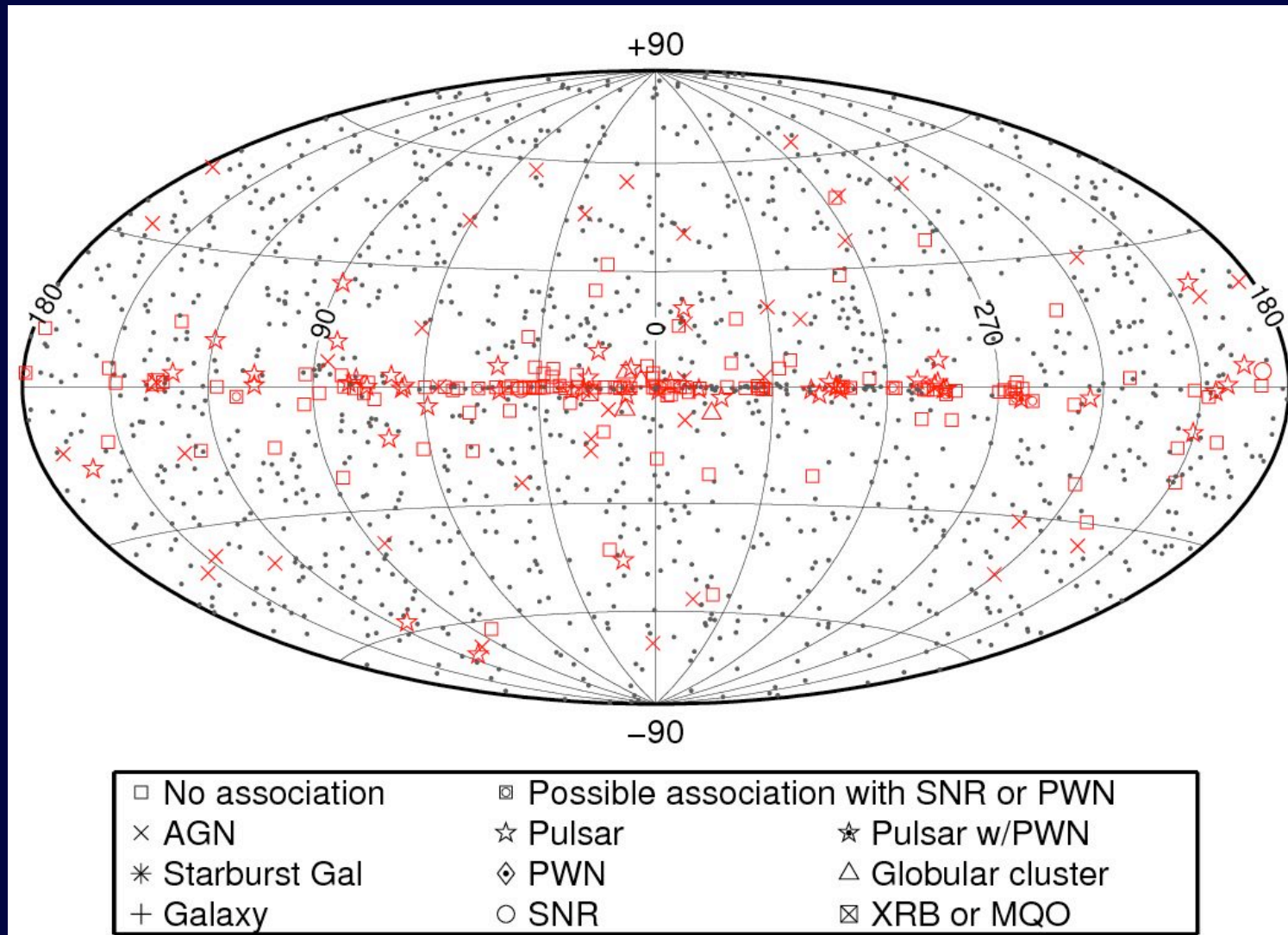
The Fermi LAT 1FGL Source Catalog

1,451 sources

Description	Designator	Number Assoc. (ID)
Pulsar, X-ray or radio, identified by pulsations	psr (PSR)	7 (56)
Pulsar, radio quiet (LAT PSR, <i>subset of above</i>)	PSR	24
Pulsar wind nebula	pwn (PWN)	2 (3)
Supernova remnant	† (SNR)	41 (3)
Globular Cluster	glc (GLC)	8 (0)
Micro-quasar object: X-ray binary (black hole or neutron star) with radio jet	mgo (MQO)	0 (1)
Other X-ray binary	hxb (HXB)	0 (2)
BL Lac type of blazar	bzb (BZB)	295 (0)
FSRQ type of blazar	bzq (BZQ)	274 (4)
Non-blazar active galaxy	agn (AGN)	28 (0)
Active galaxy of uncertain type	agu (AGU)	92 (0)
Normal galaxy	gal (GAL)	6 (0)
Starburst galaxy	sbg (SBG)	2 (0)
Unassociated		630

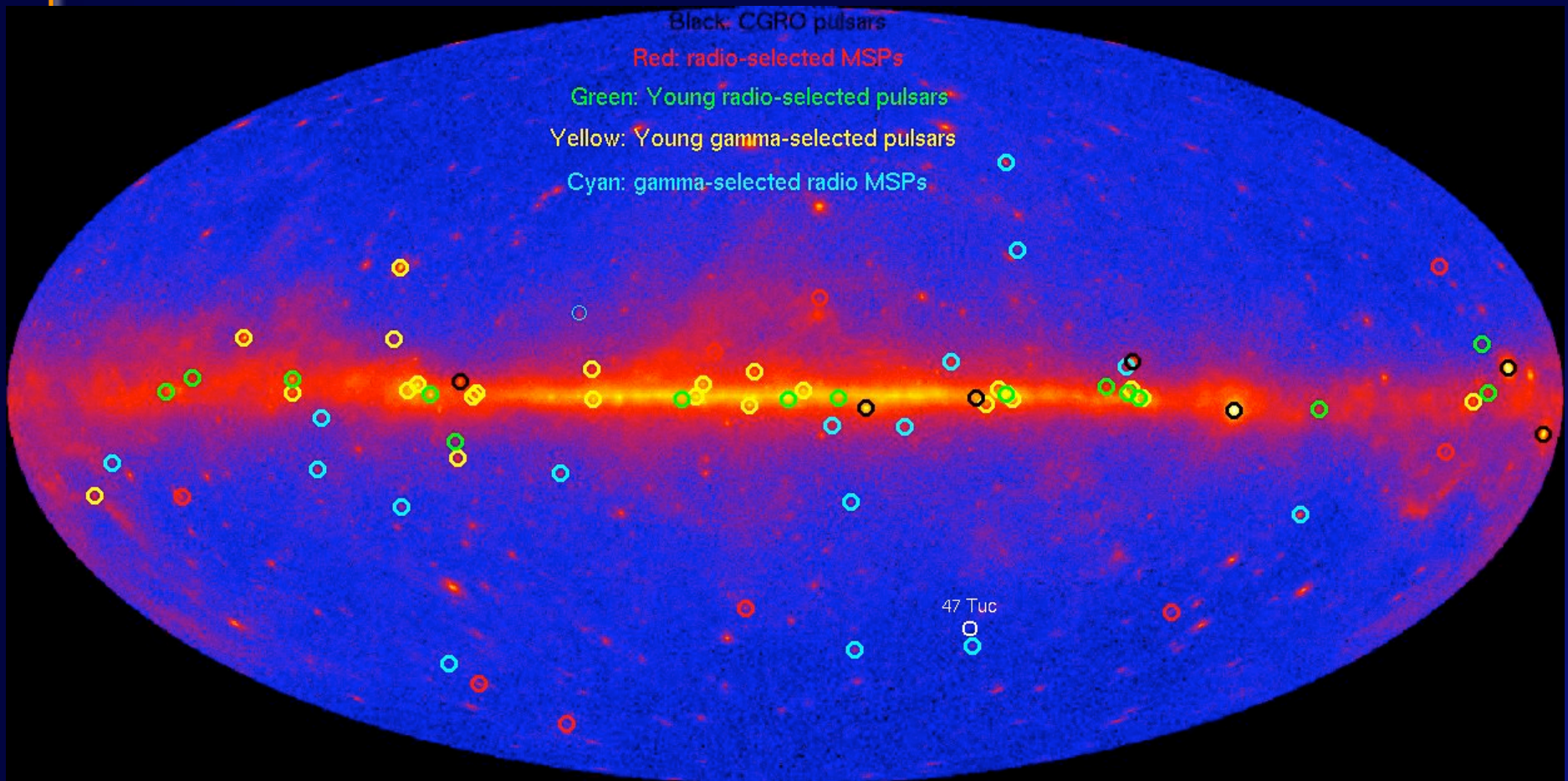
- | | |
|---|--------------------|
| ○ AGN | □ SNR |
| × AGN-Blazar | ○ PWN |
| □ AGN-Non Blazar | × PSR |
| ○ No Association | ⊗ PSR w/PWN |
| □ Possible Association with SNR and PWN | ◇ Globular Cluster |
| ○ Possible confusion with Galactic diffuse emission | × HXB or MQO |
| □ Starburst Galaxy | |
| + Galaxy | |

Curvature in 1FGL Sources





Pulsars Dominate the GeV Galaxy



More than 56 gamma-ray pulsars in the first year
Plus gamma-selected MSPs

May 28, 2010

Abdo, A. A. et al. 2010, ApJS, 187, 460

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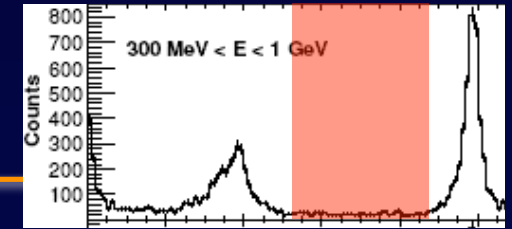


GeV PWN

✦ Which pulsars have produced bright GeV nebulae?

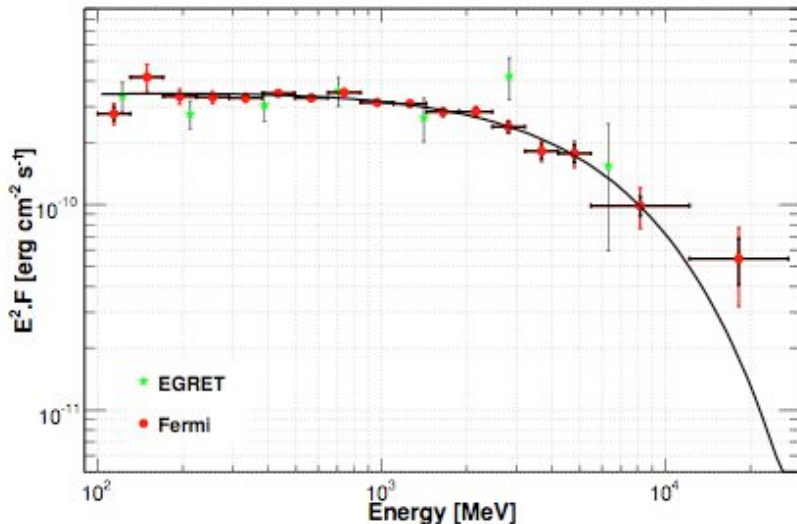


Crab Pulsar and Nebula

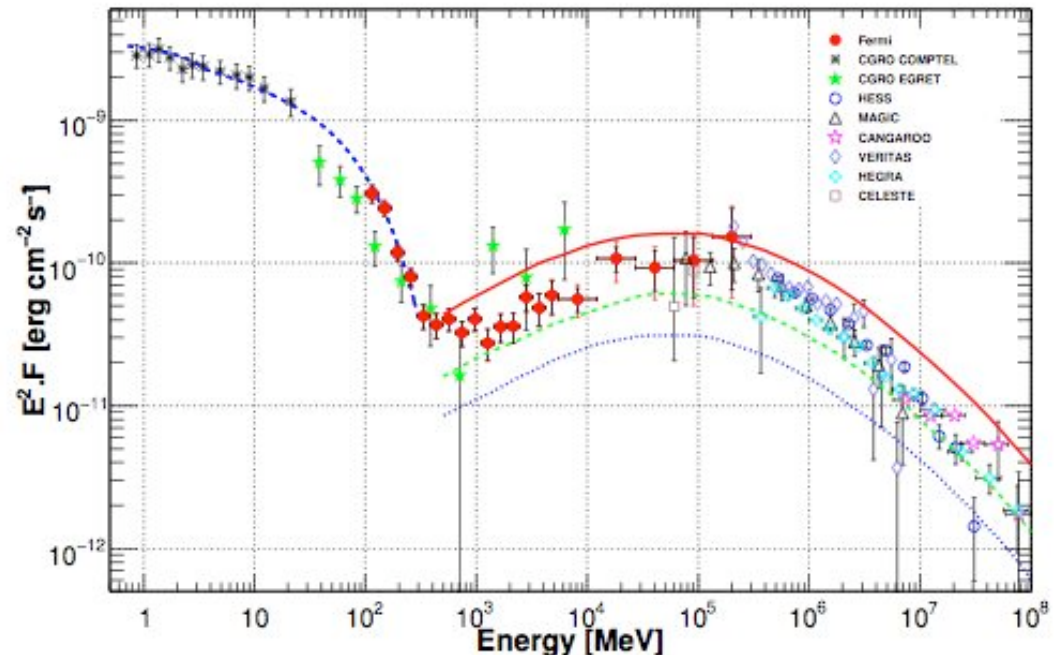


Pulsar 100 MeV to 20 GeV

Nebula from MeV to TeV

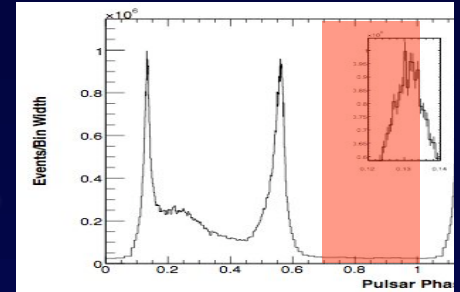


Hyper-exponential cutoff
excluded at ~ 5 sigma.
Consistent with emission
well above the neutron
star surface

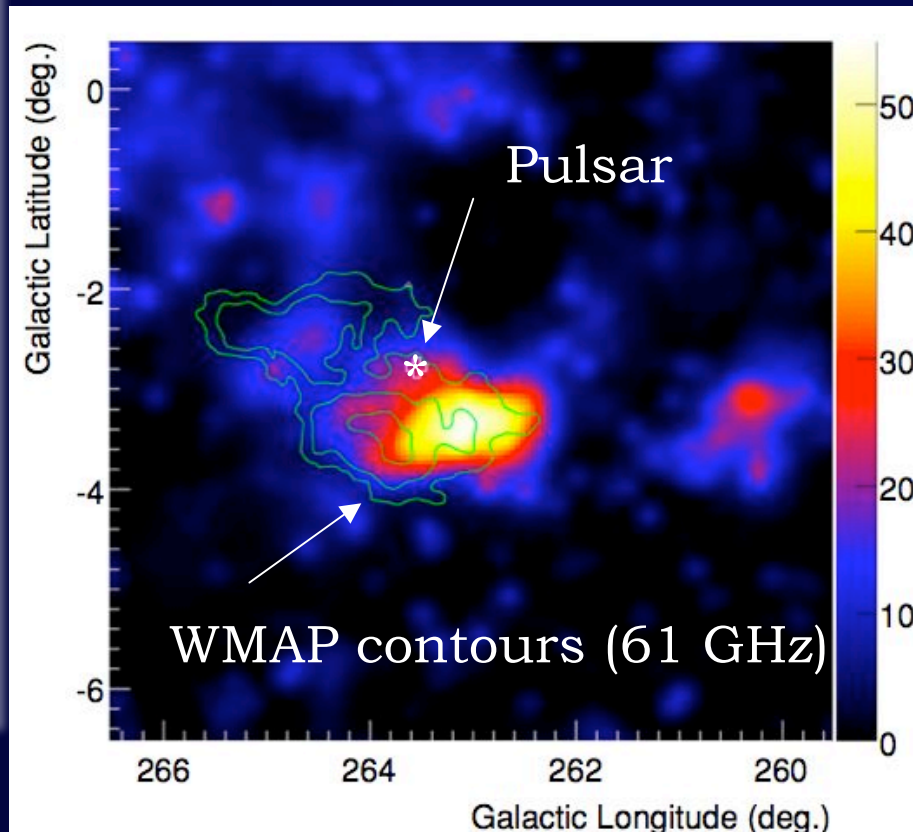


Inverse Compton emission
consistent with mean magnetic field
in nebula $100 \mu\text{G} < B < 200 \mu\text{G}$

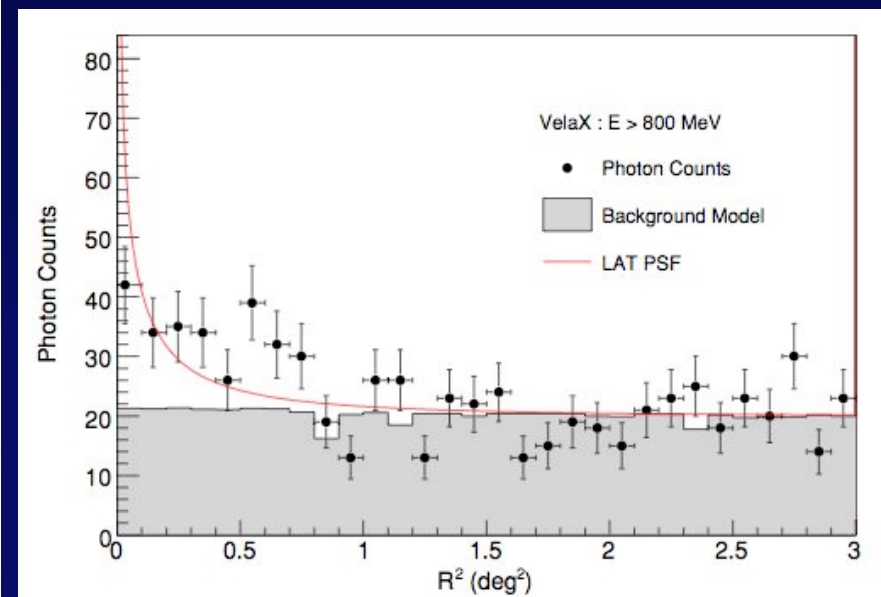
Vela X Nebula of Vela Pulsar



LAT Test Statistic Map



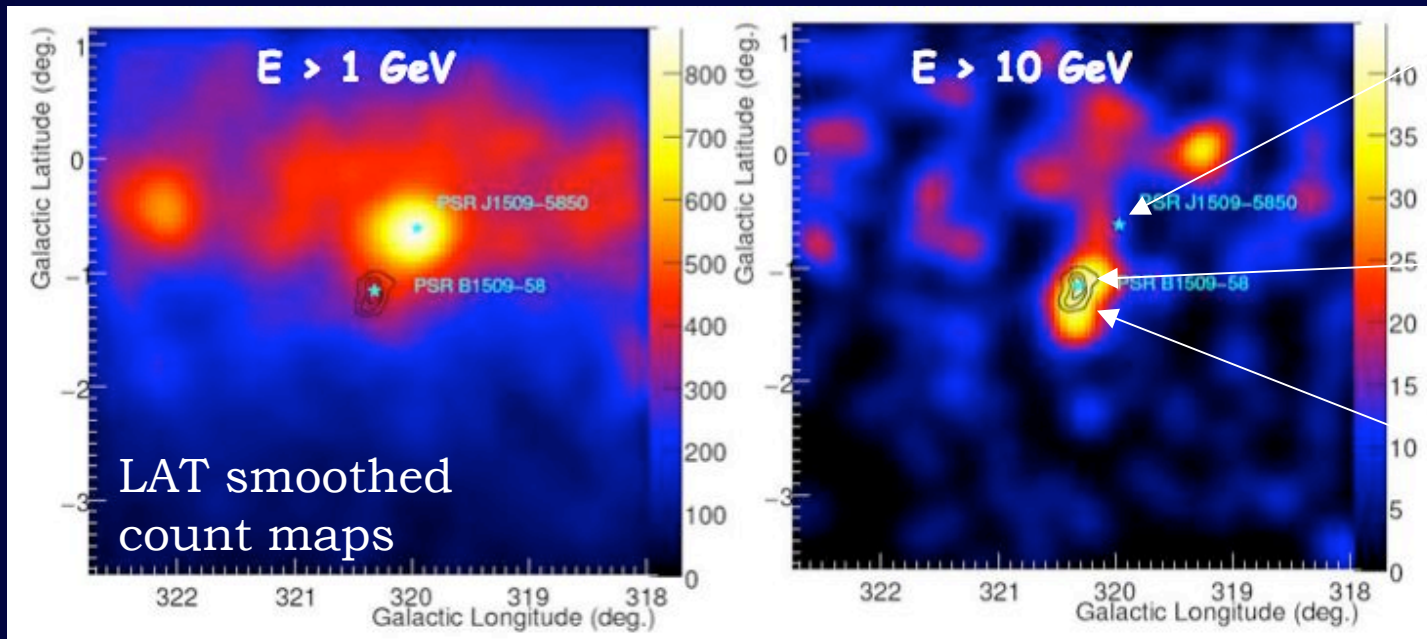
Radial Profile above 800 MeV



GeV significantly extended
 Disk radius = $0.88^\circ \pm 0.12$

Better match to radio than TeV

MSH 15-52



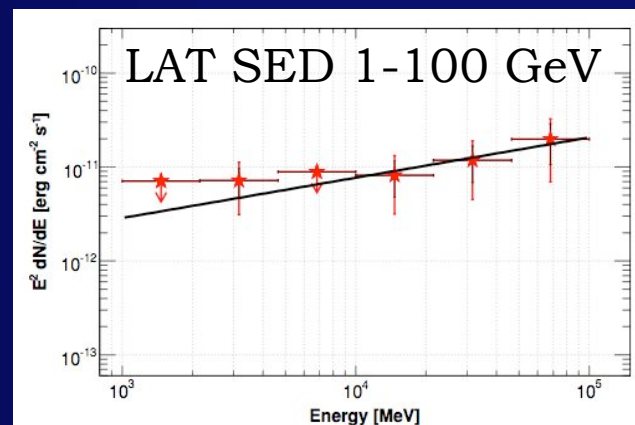
PSR
J1509-5850

PSR
B1509-58

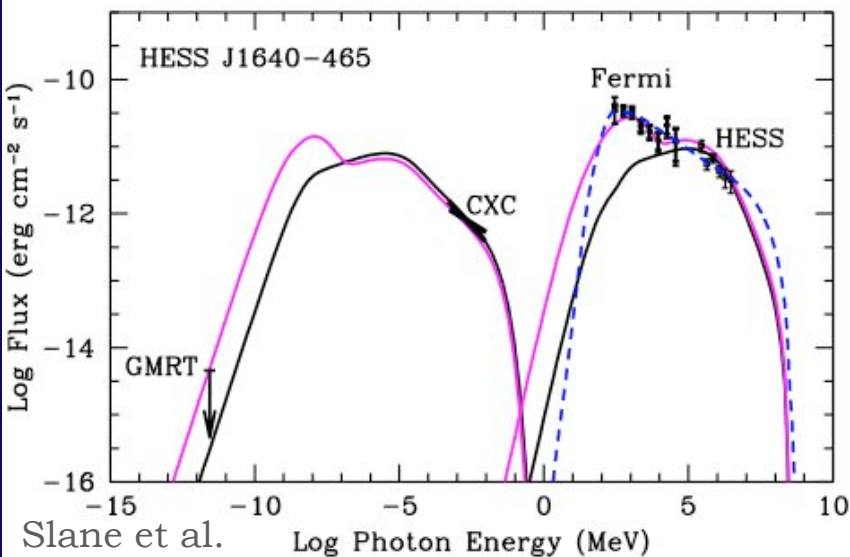
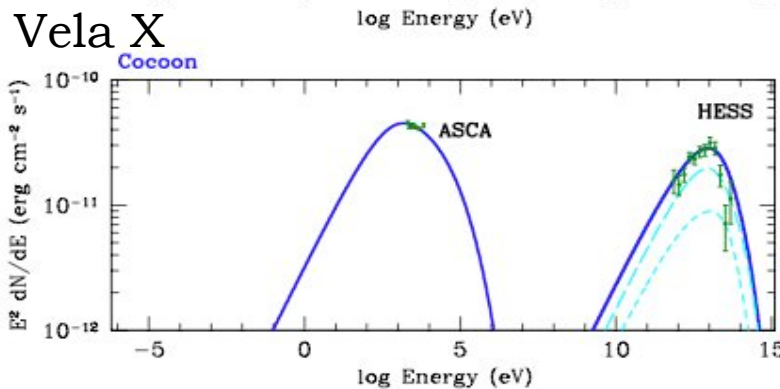
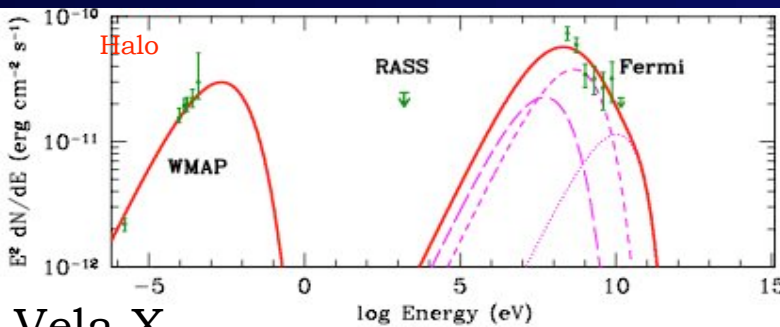
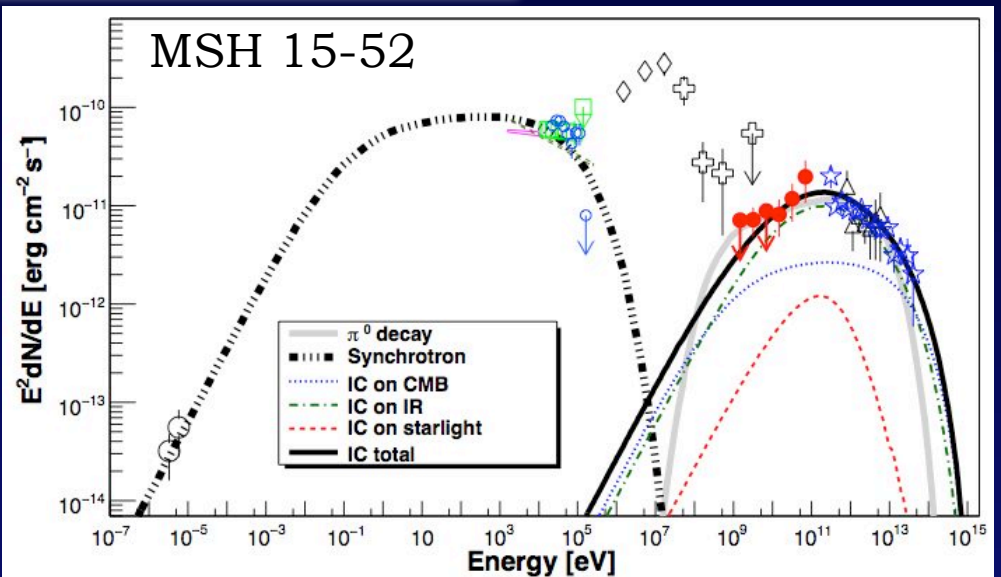
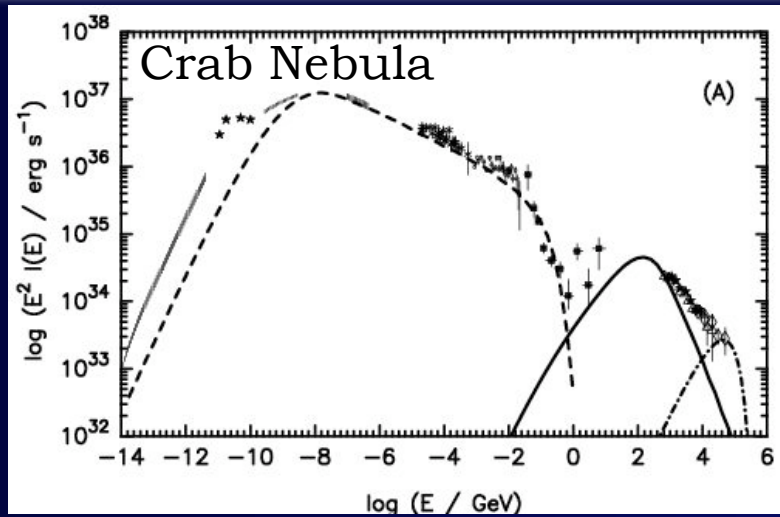
HESS
contours

PSR B1509-58 only
detected in timing analysis

Nebula not significant
below ~1 GeV



GeV PWNe Spectra

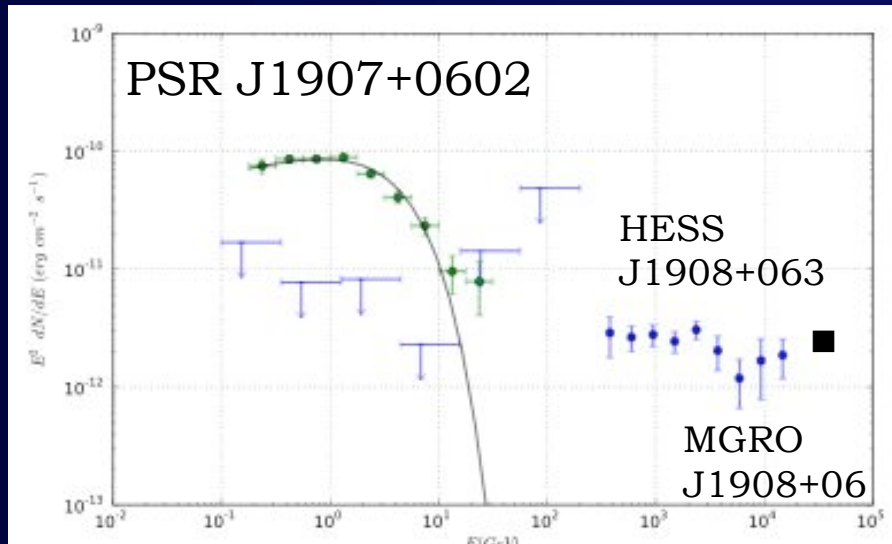


Slane et al. (submitted to ApJ)

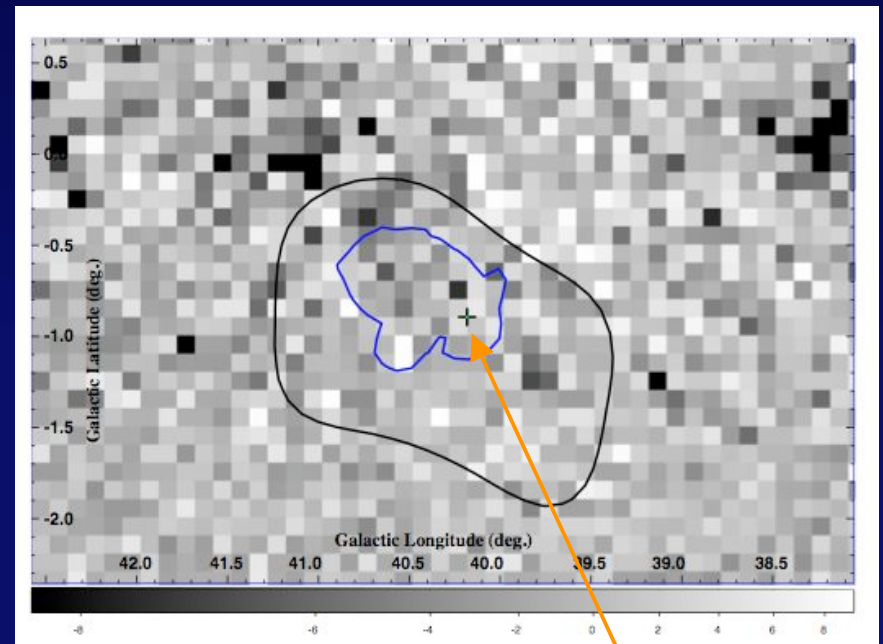
GeV Nebula Limits

PSR J1907+0602

- $\dot{E} = 2.8 \times 10^{36}$ erg/s
- Char. Age = 19.5 kyr
- Distance estimate = 3 kpc



LAT residual map
Off-pulse selection

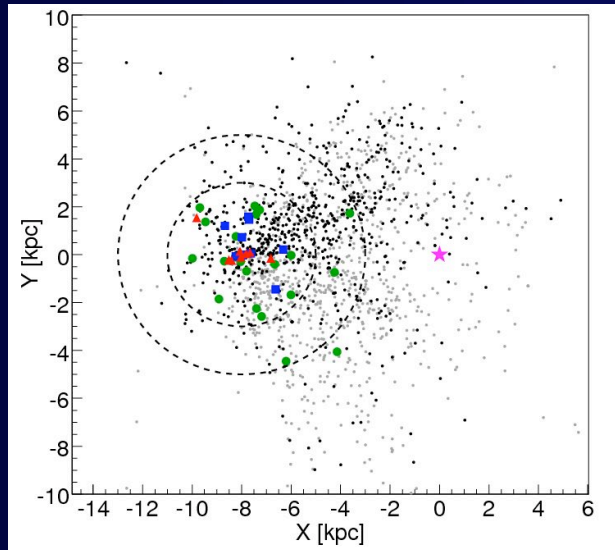


PSR J1907+0602

GeV upper limits require a low energy turnover between 20 and 300 GeV

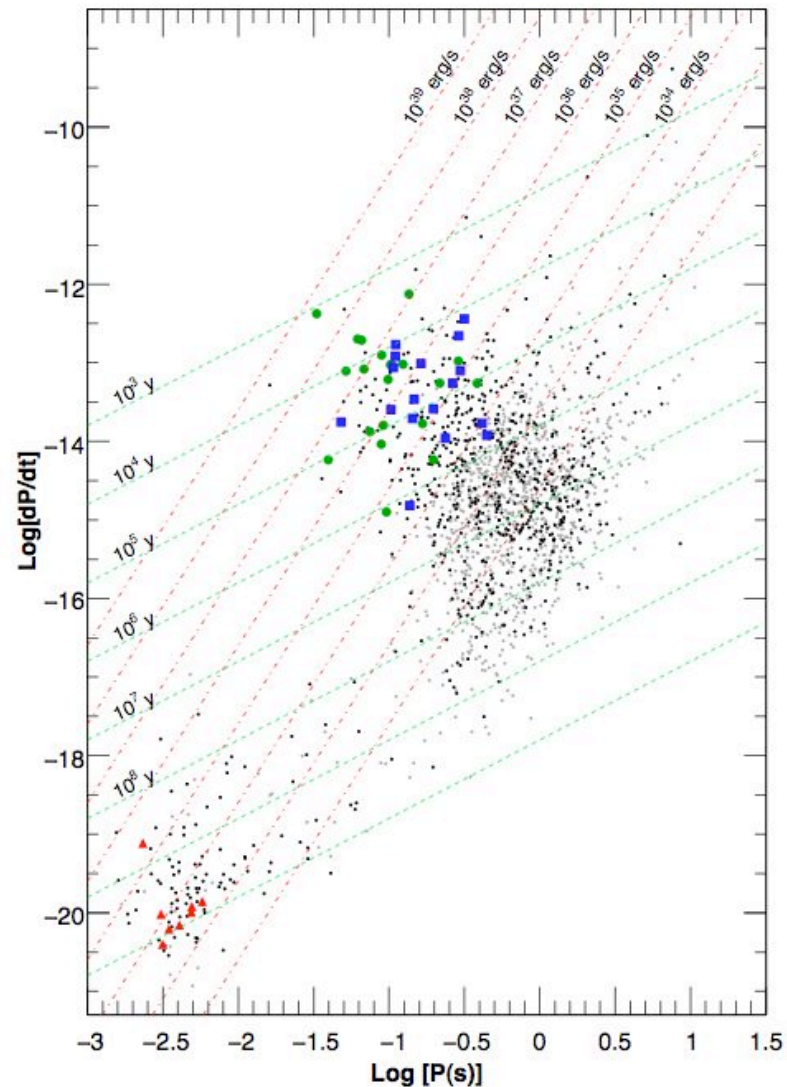
Nebula Search of LAT Pulsars

LAT is producing a more complete sample of young, energetic, nearby pulsars



Catalog under development to characterize off-pulse nebula components for the LAT pulsars

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GeV PWNe

- ✦ Detected high Edot and Crab-like and Vela-like PWNe
 - ✦ But more high Edot pulsars in both categories with undetected GeV nebulae emission
- ✦ Hard to directly associate GeV catalog with the TeV nebula catalog because of the pulsars, but clear that PWN are not a GeV population at the sensitivity of the LAT - why not?
- ✦ What is special about the LAT subset?



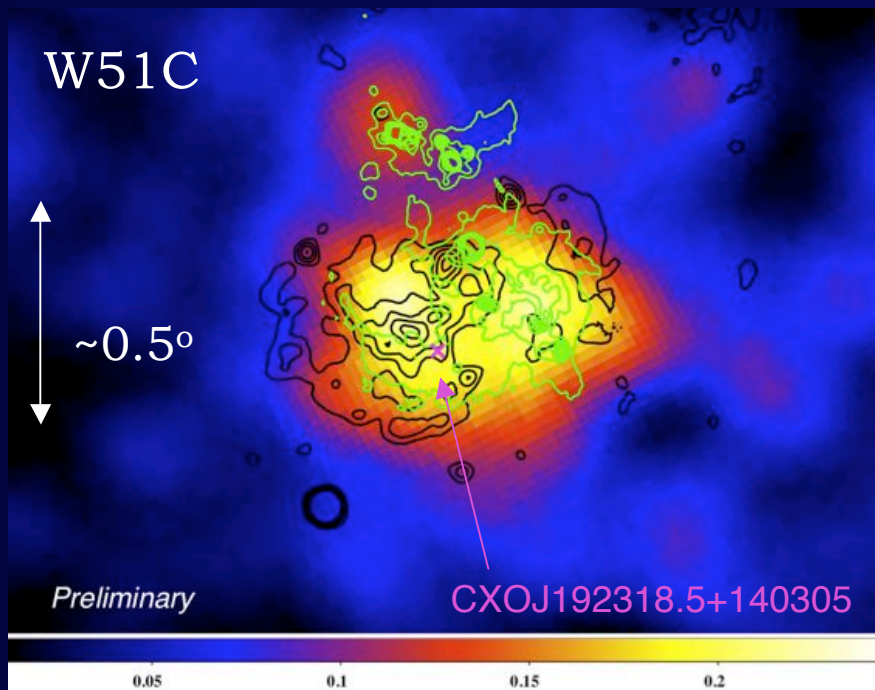
Supernova Remnants

✦ Which remnants are GeV emitters?



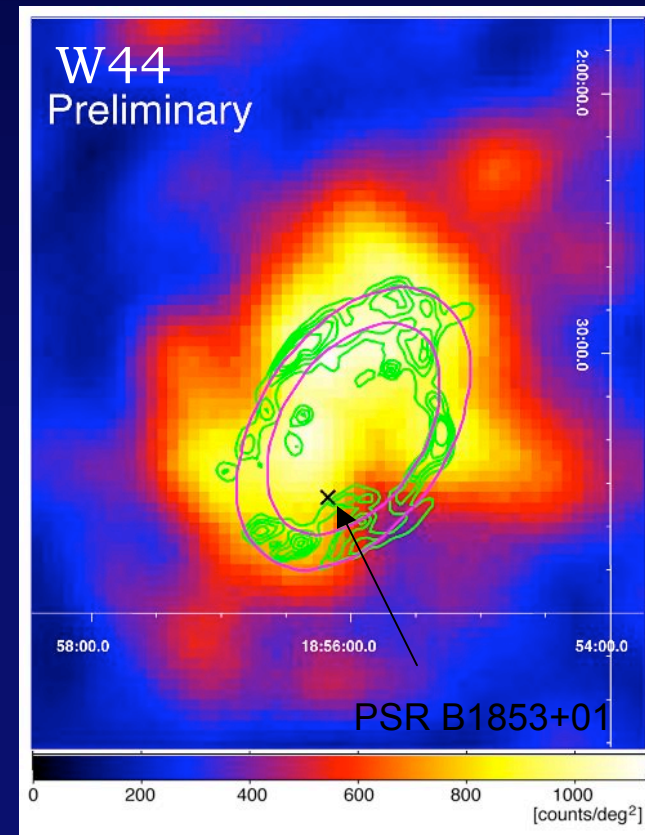
SNR: GeV Morphology

SNRs W51C, W44, IC 443, W28 North source resolved by LAT.
Cas A unresolved.
Good agreement with shell structures.



LAT counts map (2-8 GeV)
X-ray (0.1-2.4 keV, black) and
radio (1.4 GHz, green) contours

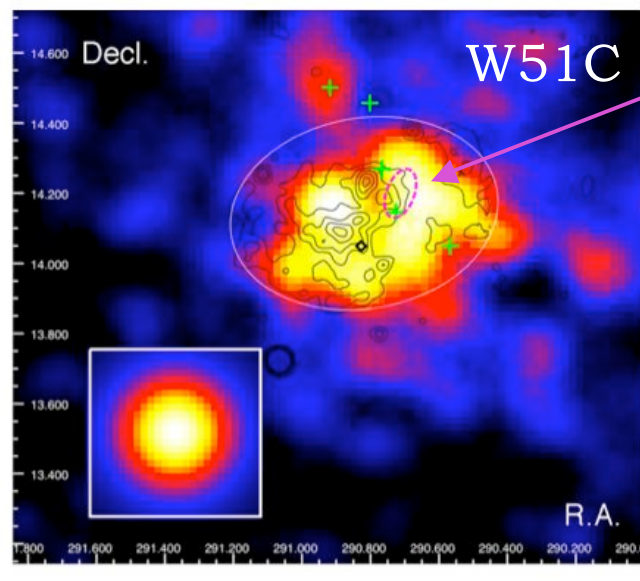
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LAT counts (2-10 GeV)
Infrared contours (4.5 μ m)

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SNR: Molecular Connection



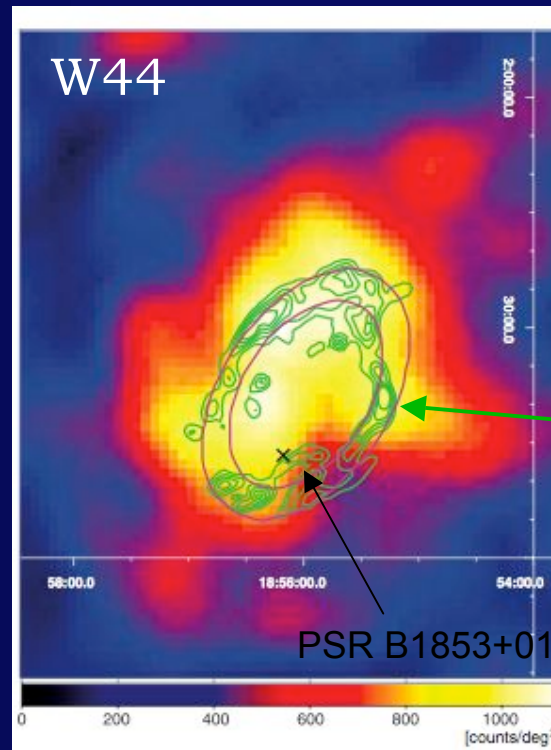
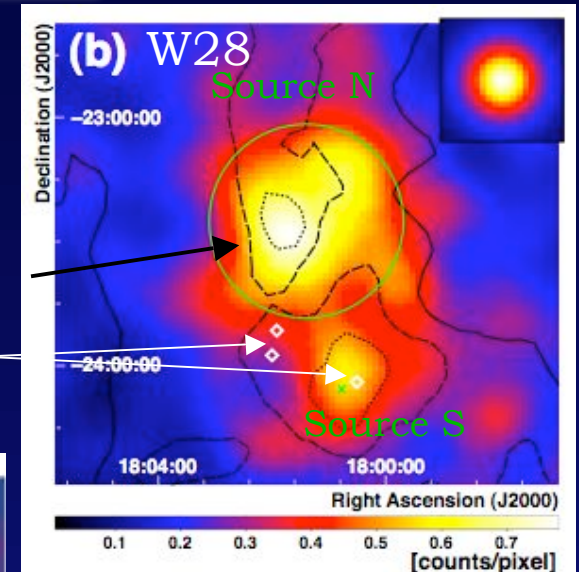
Shocked
CO

CO (J=1-0)
contours NANTEN

H II regions

GeV emission from
SNRs interacting
with molecular
clouds
IC 443, W51C, W44,
W28...

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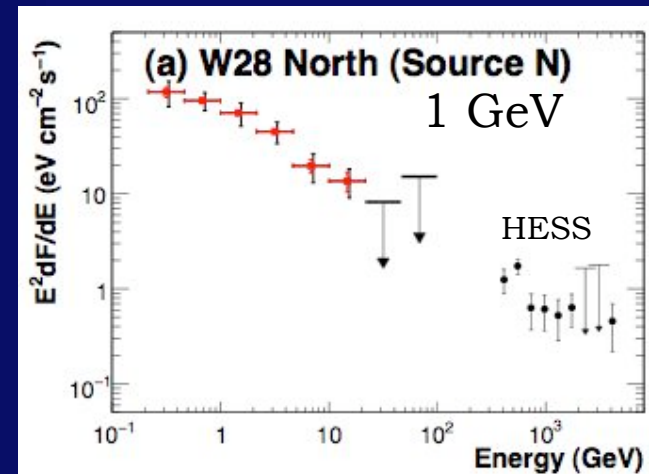
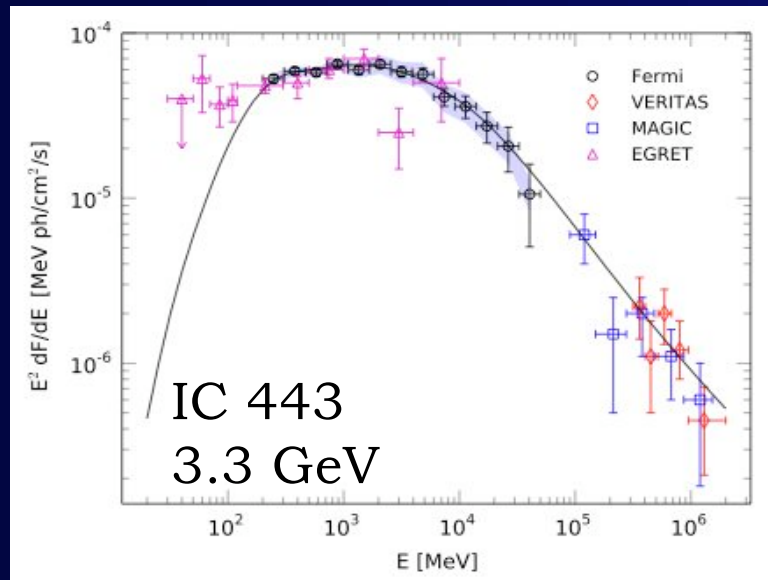
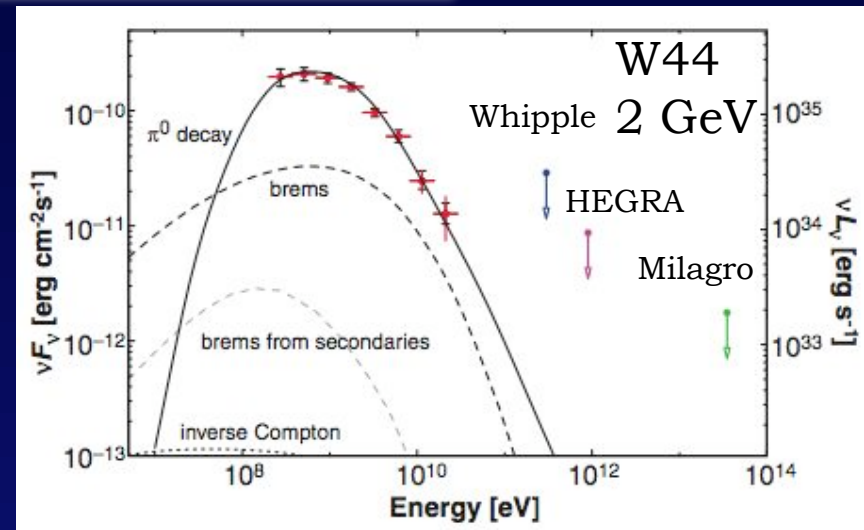
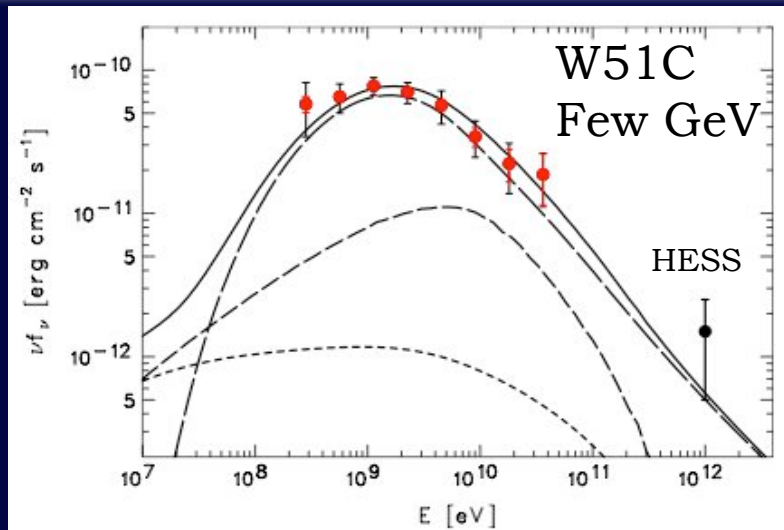


W44

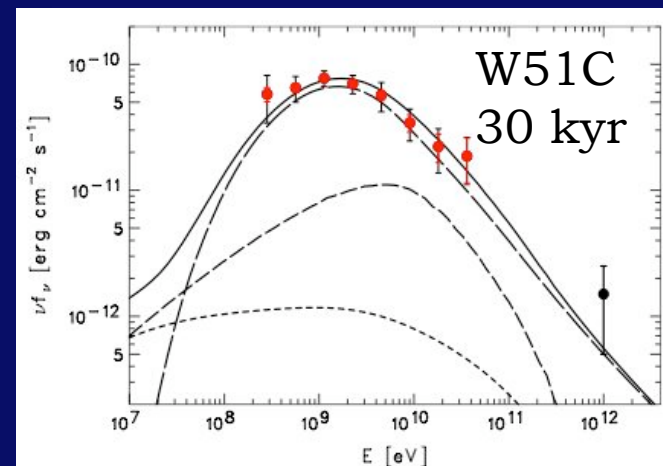
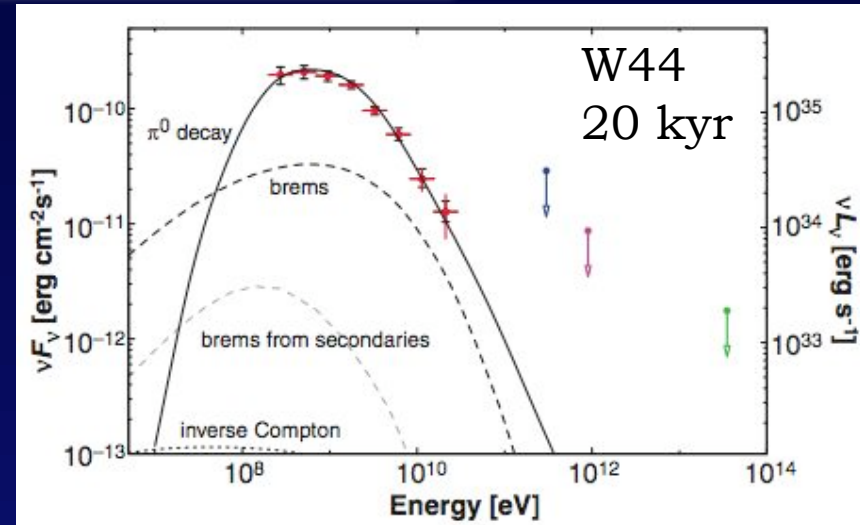
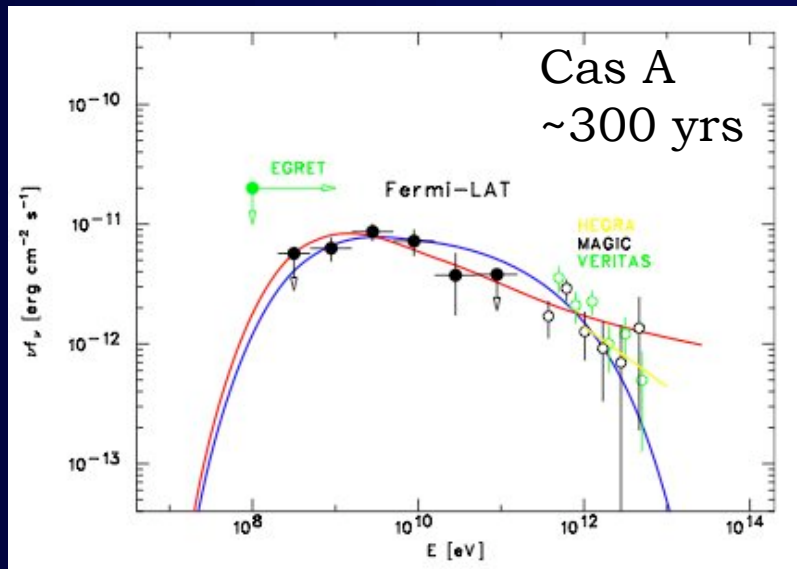
Shocked H2

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SNR: GeV Breaks



SNR: Young and Older





SNR: GeV and TeV

- ✦ Are TeV sources GeV sources?
 - ✦ Yes - >40% of TeVCat sources (diameter<40') from formal 1FGL source association
- ✦ Are SNR gamma-ray sources?
 - ✦ some
- ✦ Are TeV SNR also GeV SNR?
 - ✦ some
 - ✦ (1FGL population protocol does not support them as a GeV population)
- ✦ Do GeV and TeV probe the same remnant population?
- ✦ What defines the subset of SNR that are bright in gamma rays?



Summary

- ✦ GeV SNR class growing
 - ✦ Some preference for middle-aged remnants near dense regions (only young SNR at high significance is Cas A)
 - ✦ Pion decay scenarios generally favored; leptonic scenarios not completely ruled out
- ✦ GeV PWNe
 - ✦ Morphology and spectral studies for the bright elite
 - ✦ Multiwavelength context, particularly with TeV and radio/WMAP, probes emitting electrons
 - ✦ Population not well-defined
- ✦ Both of these classes benefit from additional LAT exposure

<http://fermi.gsfc.nasa.gov>

Extras



Fermi LAT Collaboration

✦ France

- IN2P3, CEA/Saclay

✦ Italy

- INFN, ASI, INAF

✦ Japan

- Hiroshima University
- ISAS/JAXA
- RIKEN
- Tokyo Institute of Technology

✦ Sweden

- Royal Institute of Technology (KTH)
- Stockholm University

✦ United States

- Stanford University (SLAC and HEPL/Physics)
- University of California at Santa Cruz - Santa Cruz Institute for Particle Physics
- Goddard Space Flight Center
- Naval Research Laboratory
- Sonoma State University
- Ohio State University
- University of Washington

Principal Investigator:
Peter Michelson (Stanford University)

~390 Scientific Members (including 96
Affiliated Scientists, plus 68 Postdocs
and 105 Students)

Managed at SLAC



The Fermi Observatory

Large Area Telescope (LAT)

- ♦ Large field of view (>2.4 sr)
- ♦ Entire sky every 3 hrs (every 2 orbits)
- ♦ Broad energy range (20 MeV - >300 GeV)



Gamma-ray Burst Monitor (GBM)

- ♦ Views entire unocculted sky
- ♦ **NaI**: 8 keV - 1 MeV
- ♦ **BGO**: 150 keV - 40 MeV



Large Area Telescope (LAT)

Large Field of View >2.4 sr
Broad Energy Range 20 MeV - >300 GeV

ACD

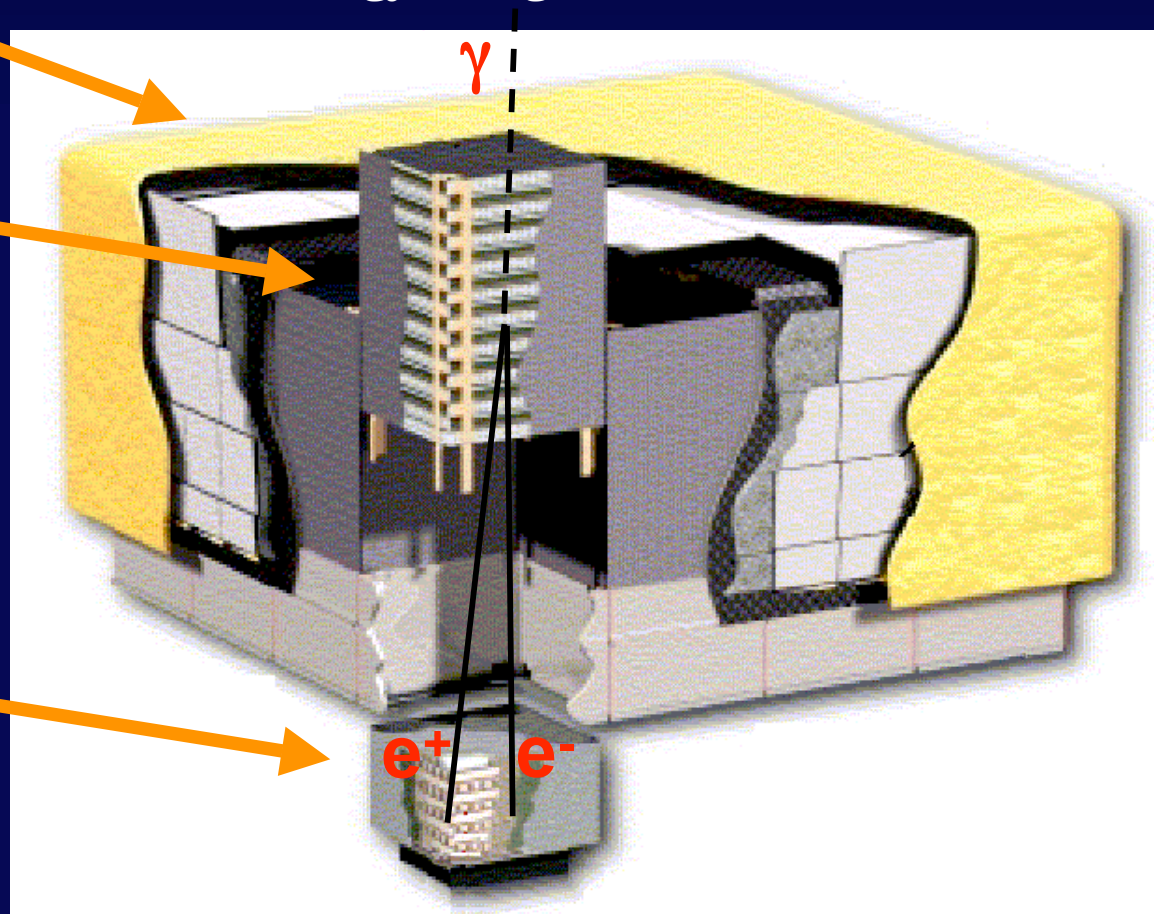
scintillator
89 tiles

Tracker

Si strip detectors
Tungsten foil
converters
pitch = 228 μm
 8.8×10^5 channels
18 planes

Calorimeter

CsI crystals
hodoscopic array
 6.1×10^3 channels
8 layers



4x4 detector array



LAT Sensitivity with Time

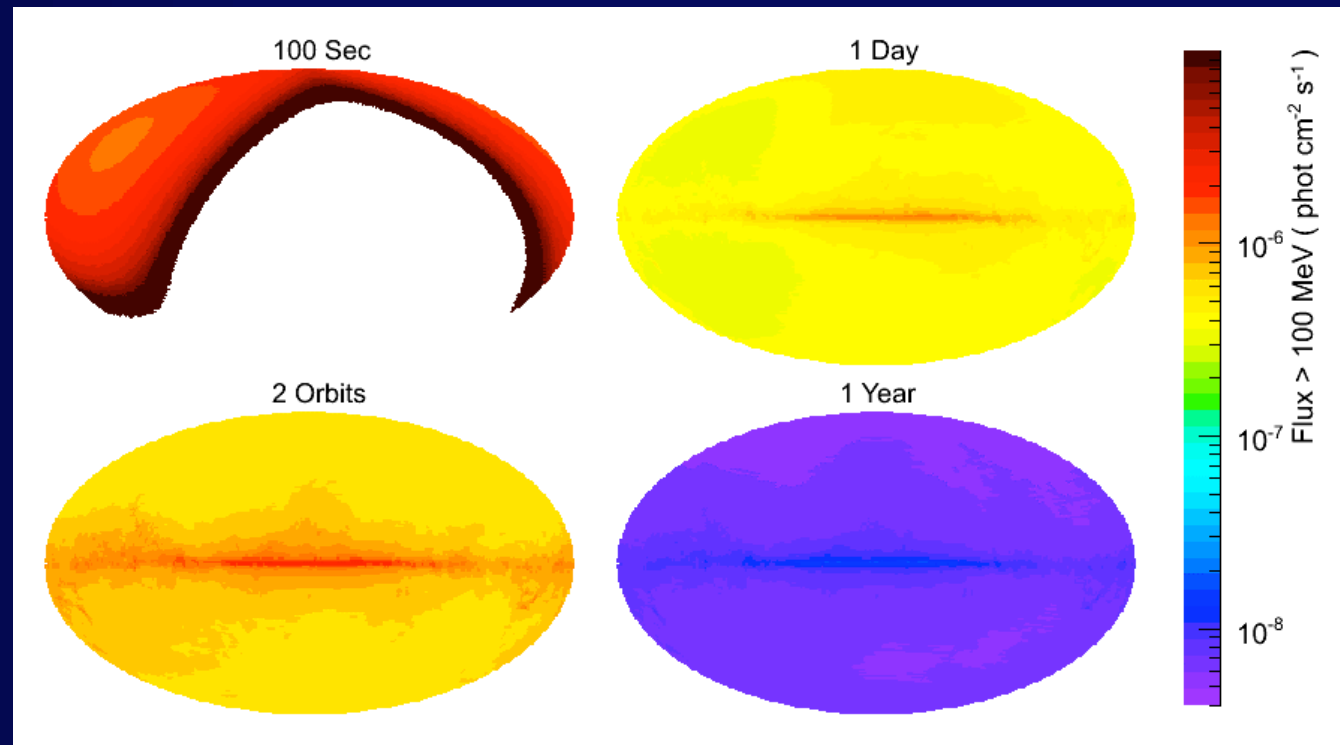
Transient Science: Flares, bursts, multiwavelength campaigns, unidentified transients

Accumulated Science: New source types, populations, long-term monitoring, spatially extended and diffuse studies

Deepest and most uniform survey of the sky at these energies

All-sky coverage
in ~3 hrs
(2 orbits)

Minor asymmetry
due to passages
through South
Atlantic Anomaly



A GeV, wide-field Instrument

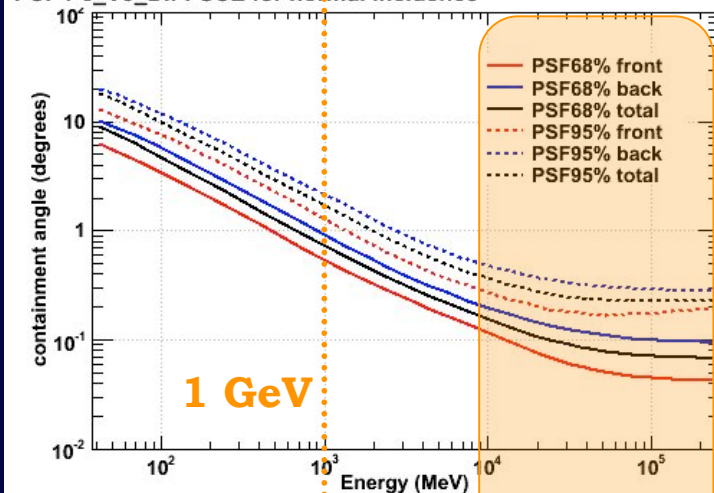
68% Containment

Effective Area

Energy Dependence

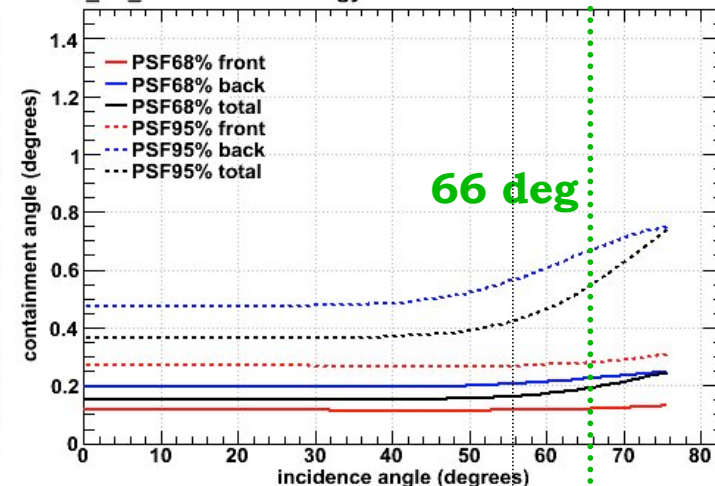
Incidence Angle Dependence

PSF P6_V3_DIFFUSE for normal incidence



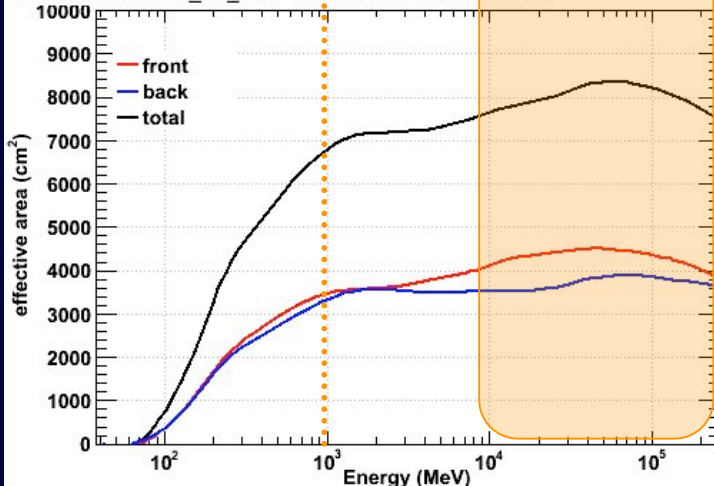
1 GeV

PSF P6_V3_DIFFUSE for energy = 10000 MeV

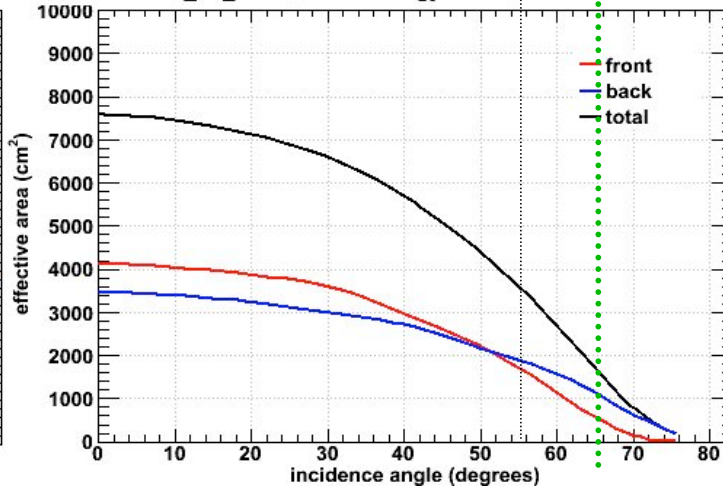


66 deg

effective area P6_V3_DIFFUSE for normal incidence



effective area P6_V3_DIFFUSE for energy=10000 MeV

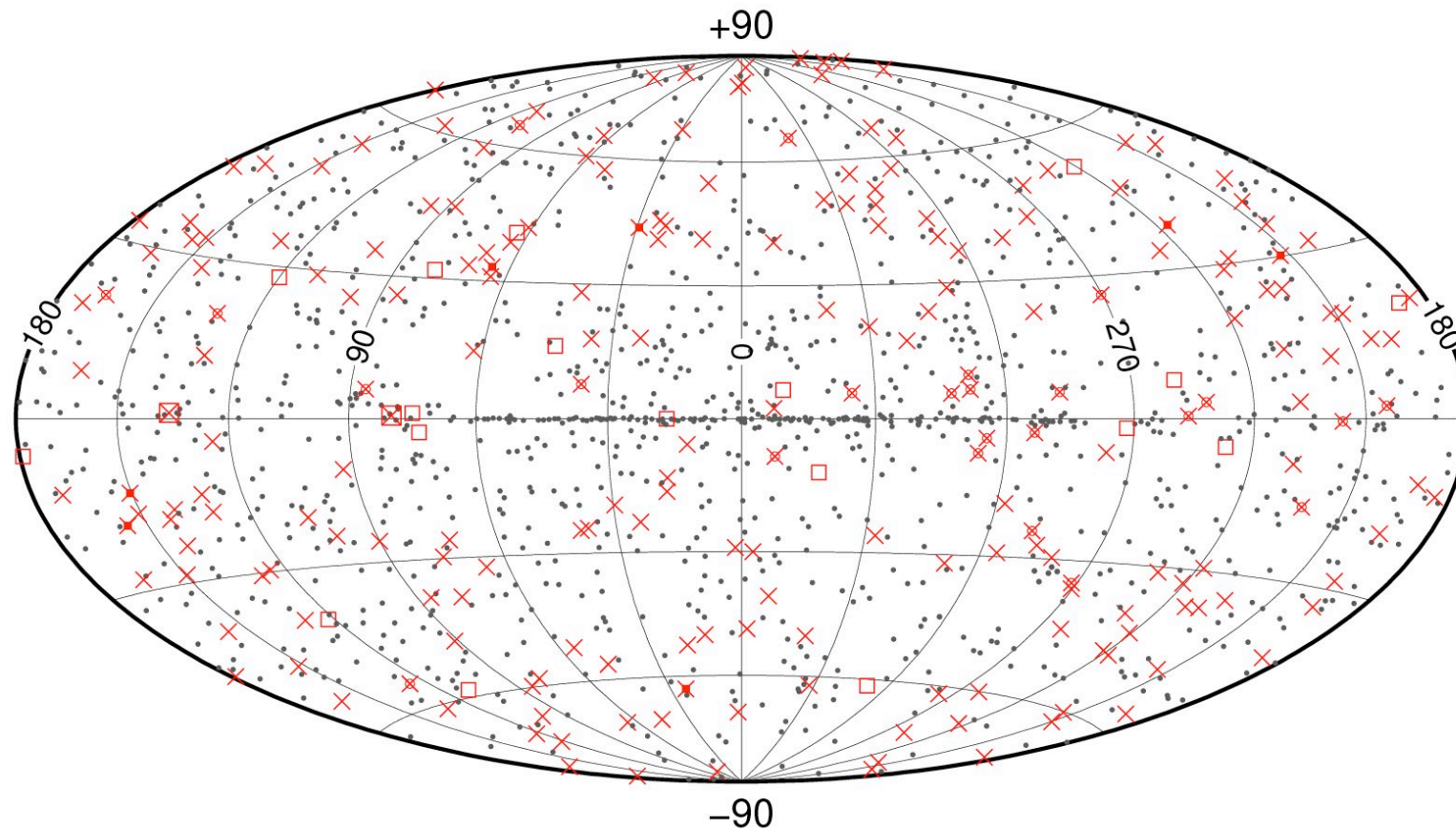




Unidentified Gamma-ray Sources

- ✦ Previous MeV-GeV energy gamma-ray missions left a legacy of “unidentified” sources (~2/3 of 3EG catalog)
 - ✦ Unidentified meant multiple possible candidates OR no plausible candidates (unassociated)
- ✦ **LAT first catalog <50% unassociated**
- ✦ LAT associations greatly aided by
 - ✦ Dramatically improved gamma-ray localization
 - ✦ Dedicated catalogs of potential gamma-ray counterparts
 - ✦ Multiwavelength searches
- ✦ LAT identifications from
 - ✦ Periodicity
 - ✦ Spatial morphology
 - ✦ Correlated variability with other observations

Variability in 1FGL Sources



- | | | | |
|--------------------|---|--------------|--------------------|
| □ No association | ◻ Possible association with nearby SNR or PWN | | |
| × AGN – blazar | * Starburst Gal | ☆ Pulsar | ★ Pulsar w/PWN |
| ⊗ AGN – unknown | + Galaxy | ◊ PWN | △ Globular cluster |
| ⊠ AGN – non blazar | ○ SNR | ⊠ XRB or MQO | |

Spectral-Variability Classification

- ✦ Blazars and pulsars in the variability-spectral curvature plane

